

Westinghouse Advanced Particle Filter System

T. E. Lippert (wx-lippert@westinghouse.com; 412-256-2440)
G. J. Bruck (wx-bruckgj@westinghouse.com; 412-256-2102)
Z. N. Sanjana (wx-sanjana@westinghouse.com; 412-256-2231)
M. A. Alvin (wx-alvinma@westinghouse.com; 412-256-2066)
R. A. Newby (wx-newbyra@westinghouse.com; 412-256-2210)
Westinghouse Electric Corporation
Science and Technology Center
1310 Beulah Road
Pittsburgh, PA 15235

Abstract

Integrated Gasification Combined Cycles (IGCC) and Pressurized Fluidized Bed Combustion (PFBC) are being developed and demonstrated for commercial, power generation application. Hot gas particulate filters are key components for the successful implementation of IGCC and PFBC in power generation gas turbine cycles. The objective of this work is to develop and qualify through analysis and testing a practical hot gas ceramic barrier filter system that meets the performance and operational requirements for these applications.

This paper reports on the development and status of testing of the Westinghouse Advanced Hot Gas Particle Filter (W-APF) including:

- Approximately 3700 hours of testing that has now been completed at the Foster Wheeler 10 MW PCFB facility located in Karhula, Finland.
x
- Operation of the W-APF in conjunction with the Foster Wheeler Advanced HIPPS Test Program being conducted at their Livingston, New Jersey site.
x
- Approximately 740 hours of operation of the W-APF at the SCS/PSDF site on the MWK transport reactor test loop.
x
- The design, installation and startup status of the W-APF unit supplied to the 95 MW Pinon Pine IGCC Clean Coal Demonstration, Reno, Nevada.
x
- The status of the Westinghouse development and testing of HGF's for Biomass Power Generation.

Results reported include operating history, operating characteristics and filter performance. Schedules and objectives for future testing are summarized.

Introduction

High temperature particulate filters are a key component in advanced, coal based gas turbine cycles (IGCC, Integrated Gasification Combined Cycle and PFBC, Pressurized Fluidized Bed Combustion) that are currently under development by DOE/FETC (Federal Energy Technology Center) for clean coal demonstration. In these applications the hot gas particulate filter protects the downstream heat exchanger and gas turbine components from particle fouling and erosion effects and cleans the gas to meet particulate emission requirements. Both PFBC and IGCC plants benefit because of lower cost downstream components, improved energy efficiency, lower maintenance and the elimination of additional and expensive flue gas treatment systems.

IGCC Systems

In IGCC systems, the hot gas particulate filter must operate in reducing gas conditions (i.e., presence of H_2 , CH_4 , CO), high system pressure (150 psi to 350 psi) and at operating temperatures usually determined by the method of sulfur removal, i.e., in bed, external or by cold gas scrubbing. Typically, these temperatures range around 1650°F (in bed), 900 to 1200°F (external) and 1000°F to 500°F (cold scrubbing).

In gasification applications, cold scrubbing of the fuel gas has been demonstrated as effective in cleaning the fuel gas to meet turbine and environmental requirements. However, with this process, plant energy efficiency is reduced, and higher capital costs are incurred. Incorporating a hot particulate filter upstream of the scrubbing unit reduces heat exchanger costs and provides for dry ash handling (partial hot gas cleaning).

Hot fuel gas cleaning concepts (in bed and external) have also been proposed that utilize reactive solid sorbents to remove gas phase sulfur and hot gas filters to collect the ash and sorbent particles. This approach in IGCC provides for highest energy efficiency and lowest cost of electricity.

IGCC systems may utilize air or oxygen blown entrained or fluid bed gasifiers. Specific operating conditions of the hot gas particulate filter will vary depending on these choices. In general, hot gas filter pilot plant test experience suggests that gasifier ash/char is noncohesive with relatively high flow resistance. Thus, the potential for fines re-entrainment and high filter pressure drop are reduced by selecting a relatively low design filter operating face velocity. Since the filter treats only the fuel gas component of the total gas flow, the choice of a low filter face velocity does not adversely impact economics. Typically, for a 100 MW_e IGCC system, the filter is required to treat only 6000 to 12,000 acfm, depending if the gasifier is oxygen or air blown. Inlet dust loadings may also vary widely, ranging from <1000 ppmw to 10,000 ppmw.

PFBC Systems

Bubbling bed PFBC technology is being demonstrated at commercial scale worldwide. Currently, these plants utilize high efficiency cyclones to remove greater than 95% of the ash and a ruggedized gas turbine to tolerate ash carried over from the upstream cyclones. Economic and performance

improvements in these first generation type PFBC plants can be realized with the application of hot gas particulate filters. Both the secondary cyclone(s) and stack gas ESP(s) could be eliminated saving costs and providing lower system pressure losses. The cleaner gas (basically ash free) provided with the hot gas filter, also permits a wider selection of gas turbines with potentially higher performance.

The applicability of hot gas particulate ceramic filters to PFBC technology was recently demonstrated at the American Electric Powers' Tidd PFBC 70 MW_e Clean Coal Demonstration Plant. In this project, a 10 MW_e hot gas filter slipstream was operated for approximately 6000 hrs. over a range of conditions and configurations (Hoffman, J.D., 1955). The Tidd PFBC demonstration project was completed in March 1995. For these bubbling bed PFBC applications, the hot gas filter must operate at temperatures of 1580°F and system pressures of 175 psia (conditions typical of the Tidd PFBC plant). Inlet dust loadings to the filter are estimated to be about 500 to 1000 ppm with mass mean particle diameters ranging from 1.5 to 3 µm. However, it was demonstrated in the Tidd PFBC filter slipstream, better filter performance is achieved by eliminating the PFBC primary cyclone. Filter inlet loading increased to about 18,000 ppm and particle mass mean diameter to 27 µm.

For commercial applications typical of the 70 MW_e Tidd PFBC demonstration unit, the filter must treat up to 56,600 acfm of gas flow. Scale-up to about 310 MW_e would require filtering over 160,000 acfm gas flow. For these commercial scale systems, multiple filter vessels are required.

An alternative to the bubbling bed PFBC is the circulating bed design (PCFB). In this process the hot gas filter will be exposed to higher operating temperatures (1650°F) and higher (factor of 10 or more) particle loading. Although the inlet particle loading is high, it contains a significantly coarser fraction (mass mean generally >15 µm) which helps mitigate the effect of the higher mass loading. For a 75 MW_e commercial scale circulating bed PFBC plant, gas flow to the filter is approximately 70,000 acfm. At this scale multiple vessels with modular filter subassemblies are required.

Second generation or topping PCFB is being developed and planned for demonstration and commercialization. In this plant, higher (than first generation PFBC) turbine inlet temperatures are achieved by partially devolatilizing the coal in a carbonizer unit producing a fuel gas. The char produced is transferred and burned in a circulating PFBC unit with high excess air. The hot (1600°F) vitiated air produced is used to combust the hot fuel gas to raise the combustion gas temperature to as high as 2350°F (Robertson, et al., 1989). With second generation PFBC, two hot gas filters are required. One filter is used to collect the ash and char material carried over from the carbonizer unit with the hot fuel gas. The second filter is used to remove ash and sorbent particles carried over with the hot vitiated air leaving the circulating pressurized fluidized bed combustor (CPFBC). Both filter units are required to operate at high temperatures (1200 to 1600°F) and high particle loading. The fuel gas filter will operate in reducing gas while the CPFBC filter operates in oxidizing conditions. A 95 MW_e second generation PFBC demonstration plant requires a hot fuel gas flow to its filter of about 8000 acfm and hot vitiated air flow to its filter of approximately 64,000 acfm.

Objectives

The objective of this work is to develop and qualify through analysis and testing a practical hot gas ceramic barrier filter system that meets the performance and operational requirements of Advanced, Solid Fuel Power Generation Cycles, Table 1.

Table 1 - Hot Gas Filter Application Requirements

- Effective Filter
 - Meet NSPS
 - Protect Downstream Equipment
- Operate Reliably
 - Cleanable
 - Stable Pressure Drop Characteristics
- Robust
 - Oxidizing/Reducing Environments
 - Alkali/Acid Gas
 - Thermal Cycling

The hot gas filter must remove sufficient particulate to protect the gas turbine from erosion damage, corrosion and particle deposition and meet power plant environmental standards (NSPS). Turbine tolerance estimates and current NSPS requirements are shown in Figure 1. Also shown are ceramic barrier filter outlet particle loading data from subpilot and pilot plant test facilities. This data shows the high performance potential of the hot gas ceramic filter device relative to power generation application.

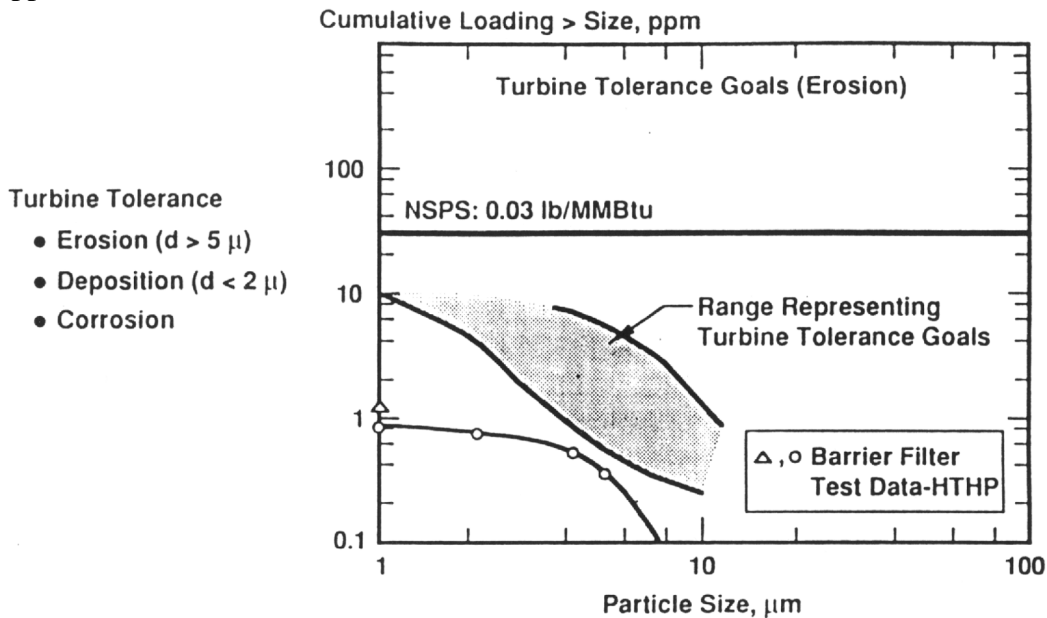


Figure 1 - Turbine Tolerance and Particulate Emission

Requirements in Coal Fueled Gas Turbine Applications

Candle, crossflow and tube filters are examples of ceramic barrier filter devices being developed for high temperature particle filtration. These filter devices are basically absolute filters on ash materials, can be operated at high throughput and can be cleaned by simple pulse jet methods.

Project Description

Background

The Westinghouse hot gas filter system development is being supported through key sub-pilot, pilot and demonstration programs, Table 2. This testing has included approximately 3290 hours of operation in reducing gas environments (gasification) and 11,800 hours in combustion (oxidizing) conditions. In addition to this field experience, over 25,000 hours of test experience has been compiled in the Westinghouse HGF, high temperature, high pressure simulators.

Table 2 - Westinghouse IGCC and PFBC Hot Gas Cleaning Testing Experience

Application	Facility	Pressure (psi)	Temperature Range (°F)	Flow (ACFM)	Dust Load (ppmw)	Test Hours
Gasification (IGCC)	Fluid bed (KRW)	131-231	1050	50-300	1,000-25,000	1300
	Texaco Gasifier	350	1000-1400	50-110	300-25,000	700
	Biomass (NREL) IGT/WHBGP	195-260	1000-1650	125	1,000-2,500	50-IGT (Continuing)
	SPPC, Pinon Pine IGCC (95 MW _e)	260	1000	13,391	18,000	Startup 1997
Combustion (PFBC)	SCS Wilsonville (MWK)	200-350	700-1500	1000-1700	4,000-40,000	737 (Continuing)
	AEP Tidd, PFBC	135	1200-1500	7,500	600-10,000	5,800
	Ahlstrom Karhula, PCFB	160	1550-1650	3,070	4,000-18,000	3,676 (Continuing)
Advanced PFBC and Indirect Cycles	FWDC Livingston	150-200	1100-1500	100-400	5,000-35,000	400 (700)* 900 (700)* 142 (Continuing)
	<ul style="list-style-type: none"> • Carbonizer • Combustor • HIPPS 	60-120	1200-1400	100-400	40,000 and higher	
	SCS/PSDF (FW-7MW _e)	200-350	1200-1650	2,000	11,000	Startup 1997

*Integrated Operation, 1995

Hot Gas Filter System

The Westinghouse hot gas filter design, schematically shown in Figure 2, consists of stacked arrays of filter elements supported from a common tubesheet structure. In this design, the arrays are formed by attaching individual candle elements (Item 1) to a common plenum section (Item 2). All the dirty gas filtered through the candles comprising this single array is collected in the common plenum section and discharged through a pipe to the clean side of the tubesheet structure. Each array of filter elements is cleaned from a single pulse nozzle source. The individual plenum assemblies (or arrays) are stacked vertically from a common support structure (pipe), forming a filter cluster (Item 3). The individual clusters are supported from a common, high alloy tubesheet structure and expansion assembly (Item 4) that spans the pressure vessel and divides the vessel into its “clean” and “dirty” gas sides. Each cluster attaches to the tubesheet structure by a specially designed split ring assembly. The cluster is free to grow down at temperatures. The plenum discharge pipes ducting the filtered gas to the clean gas side of the tubesheet structure are contained within the cluster support pipe and terminate at the tubesheet. Each discharge pipe contains an eductor section. Separate pulse nozzles are positioned over each eductor section. The eductors assist pulse cleaning. During cleaning, the pulse gas is contained within and ducted down the discharge pipe and pressurizes the respective plenum section.

The plenum assembly and cluster (stacked plenums) form the basic modules needed for constructing large filter systems indicative of PFBC requirements. The scale-up approach is:

- Increasing plenum diameter (more filter elements per array)
- Increasing the number of plenums per cluster
- Increasing the vessel diameter to hold more clusters

In general, vessel diameter will be limited by the tubesheet structure and desire to shop fabricate the vessel. Larger PFBC plants would utilize multiple vessels.

Filter Element Technology

Ceramic barrier filter devices, such as candles and cross flow filters, are under development for hot gas filter application. These devices have been shown to be basically absolute filters on ash material, can be operated at relatively high gas throughput with acceptable pressure drop and cleanable by simple reverse pulse jet methods. Clay bonded silicon carbide (SiC) candle filters are commercially available. The structure of these elements is mainly a coarse-grained SiC bonded by a clay-based binder. Each element is provided with a fine grained SiC or aluminosilicate fiber outer skin that serves as the filtration surface. Alternate, oxide-based ceramic materials are also being developed for ceramic barrier filter application. Both first generation, full-scale cross flow and candle filter elements have been constructed using a homogeneous structure that is an alumina/mullite (A/M) matrix containing a small percentage of amorphous (glass) phase. Over the past several years, Westinghouse working with DOE and various suppliers, have helped to develop and qualify alternative, advanced ceramic filter materials and candle elements. This development has included both dense and lightweight monolithic, vapor infiltrated and

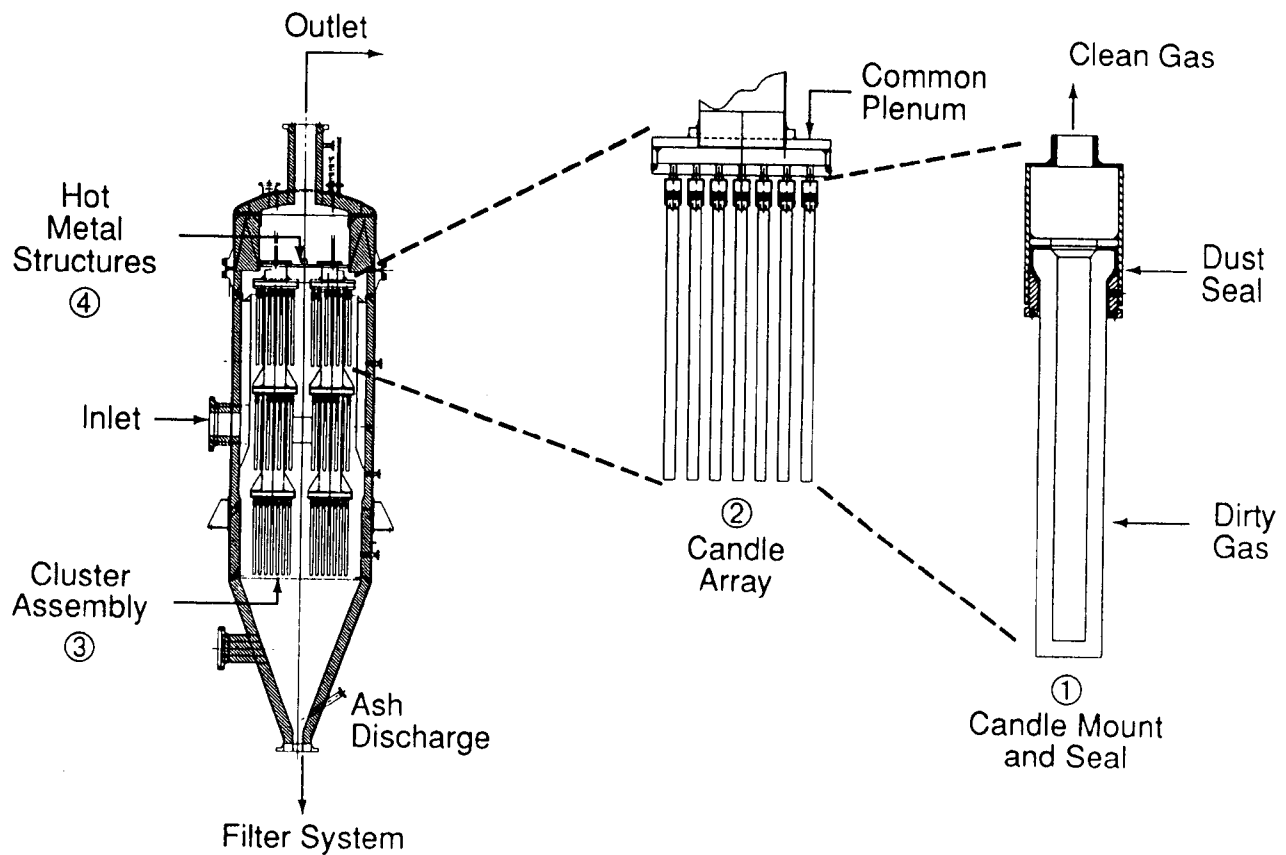


Figure 2 - Westinghouse Candle Filter System Design

Sol-Gel fiber reinforced and filament wound constructions. Laboratory and field evaluation of these and other materials are being conducted to identify, characterize and compare their respective chemical and thermal stability for IGCC and PFBC applications. The status of this work is presented in a companion paper entitled "Filter Component Assessment."

This paper updates the assessment of the Westinghouse hot gas filter design based on ongoing testing and analysis.

Approach

The development and qualification of the Westinghouse hot gas filter is being supported through key sub-pilot, pilot and demonstration projects. Test sites include government furnished and industrial facilities.

Results

Entrained Gasification

In this program, a sub-pilot scale hot gas filter was integrated with a 15 tpd Texaco entrained gasifier. The facility is located in Montebello California. The filter test program was conducted from April 1989 through August 1992 and reported (Lippert et al., 1993). Filter testing was in support of a base program that was focused on evaluating hot desulfurization technologies. In this testing, the filter was used to protect the external sulfur sorbent beds from ash plugging. This work showed that in the entrained gasification application, stable pressure drop operation can be achieved but the ceramic barrier filter system must be sized and designed for relatively low face velocity (<4 ft/min) and high operating pressure drop (>3 or 4 psi). The potential for particle re-entrainment is a key consideration in selecting the hot gas filter design and operating conditions.

Biomass IGCC/HGF Testing

A 14 candle-element HGF unit was integrated and operated with the Institute of Gas Technology's (IGT) RENUGAS biomass gasification process. The RENUGAS process is a pressurized fluidized bed, air or oxygen blown gasifier. The development and operation of the IGT's 10 ton per day process development unit (PDU) is described by Wiant, et al., 1993 and Lau, et al., 1993. The testing program at IGT utilized bagasse and alfalfa feed and was conducted in support of the DOE Biomass Power Program, and specifically the Biomass Gasification Facility Demonstration in Paia, Hawaii.

The IGT/PDU included a tar cracker that was first operated and characterized. It was concluded from this work that the majority of the oil and tar from the RENUGAS process would not crack within the pores of the filter elements if the filter temperature is maintained below 1500°F (815°C), but above the condensation temperature of the highest boiling-point components (approximately 950°F (510°C)).

The hot gas filter testing was conducted in two, one week test campaigns resulting in about 50 operational hours at conditions. A summary of the testing conditions is given in Table 3. Test Series 1 was conducted with the full 14-element complement of candle elements. In this test series, the upstream cyclone was disabled to increase particle size and solid loading to the filter unit. Particle analysis showed a 10.8 micron mass mean. This short duration test showed no operational issues, with stable baseline pressure drop. Visual inspection, following testing confirmed filter integrity and high performance level (high collection efficiency).

Test series 2 was conducted utilizing ten candle elements and with the upstream cyclone fully operational. Again, particle analysis showed that the mass mean size, 3.8 microns, now entering the filter decreased significantly compared to Test Series 1. Initially, in the Test Series 2 testing, steady filter pressure drop characteristics were observed but in the latter portion of this testing, a steady rise in the baseline pressure drop was observed, likely reflecting re-entrainment because of the smaller particle mean size. Post test inspection confirmed the filter integrity and no dust was found on the clean gas

Table 3. Biomass/IGT Hot Gas Filter Testing Summary

	<u>Test 1</u>	<u>Test 2</u>
Feed Stock	Bagasse	Bagasse
Filter Pressure	260 psig	195 to 245 psig
Filter Gas Temperature	1580 to 1650°F	1000 to 1230°F
No. of Candle Elements	14	10
Dust Loading	2900 ppm	980 to 2500 ppm
Operating Hours	21	30
Outlet Dust Loading	Not Detectable	Not Detectable
Alkali	--	0.7 to 1.0 ppm

side. These test results show that better performance will be achieved with larger particle size, thus eliminating the need for the upstream cyclone.

This 14-element HGF Test Unit has now been removed from the IGT/PDU and installed into the slipstream off the DOE's 100 ton per day Biomass Gasification Facility (BGF) located in Paia Hawaii.

Westinghouse is the prime contractor for the DOE's Hawaiian Biomass Gasification Commercialization Program. The program is facilitating the commercialization of pressurized biomass gasification combined cycle power plants. The first step in the program is the Technology Verification Phase (TVP) which will result in the accumulation of 1500 hours of testing at the Paia Hawaii site. The TVP tests at nominal commercial operating pressure and temperatures are required to demonstrate that the biomass feed system, gasifier and hot gas filter units will work as an integrated system and that the technology is ready for commercial demonstration.

The BGF is being modified to operate at pressures up to 300 psig and at throughputs of up to 100 tons per day of dry bagasse. The Westinghouse HGF system is installed in a slipstream that will filter approximately one tenth of the bagasse product gas flow from the gasifier. Pending completion of modifications (scheduled for mid-year 1997), a one month period of system shakedown will occur followed by 1500 hours of long duration testing over a five month period.

Sierra Pacific, Pinon Pine IGCC/HGF Project

Westinghouse has designed and supplied the HGF unit for the Department of Energy's Clean Coal Technology Demonstration, Pinon Pine IGCC project. The coal gasification process uses the KRW fluid bed technology owned by The M.W. Kellogg Co. who specified and purchased the filter. The final filter design evolved to satisfy the project requirements of both The M.W. Kellogg Co. and the Sierra Pacific Power Co. The plant is located at the Sierra Pacific Power Company's Tracy station near Reno, Nevada. The plant will gasify approximately 880 tons/day of coal using the KRW air blown gasification process to produce about 95 MWe. The plant is scheduled to begin commercial operation on coal in 1997. The gasification island portion of the plant is currently undergoing shakedown in preparation for coal operation.

Table 4 summarizes the design basis for the HGF unit. The unit is schematically shown in Figure 3. The filter consists of 784 candle elements, arrayed on four clusters. Each cluster contains 187 candles distributed over four plenums.

Table 4 - SPPC -Pinon Pine HGF Design Basis

Gas Environment:	Reducing
Gas Flow:	307,800 lb/hr
Pressure:	260 psi
Gas Temperature:	1011°F
Inlet Dust Loading:	18,400 ppm
Max. Pressure Drop:	9 psi (max.)

For commercial operation, the Filter is designed for maintainability. Access into the filter body is provided by four, 36 inch diameter manways. Two diametrically opposite manways are positioned between clusters to access the top level of plenums. Similarly, two diametrically opposite manways are positioned between clusters to access the lower middle level of plenums. Platforms were designed to bolt to the manway flanges to provide staging for personnel to stand inside the vessel for in-situ service work. Below each manway a set of vertically oriented rails are provided. Ladders treads are strung between the rails to provide access to the lower plenum service area. Personnel climb down the ladder and work off a second platform. The arrangement is illustrated in Figure 4. At any given platform location, all filters for two adjacent plenums are accessible by rotating the associated cluster. Such rotation is accomplished by entering the vessel head above the tubesheet, disengaging the cluster top flange from the tubesheet and with standard manual rigging attached between the vessel head and cluster top flange, lifting and rotating the cluster.

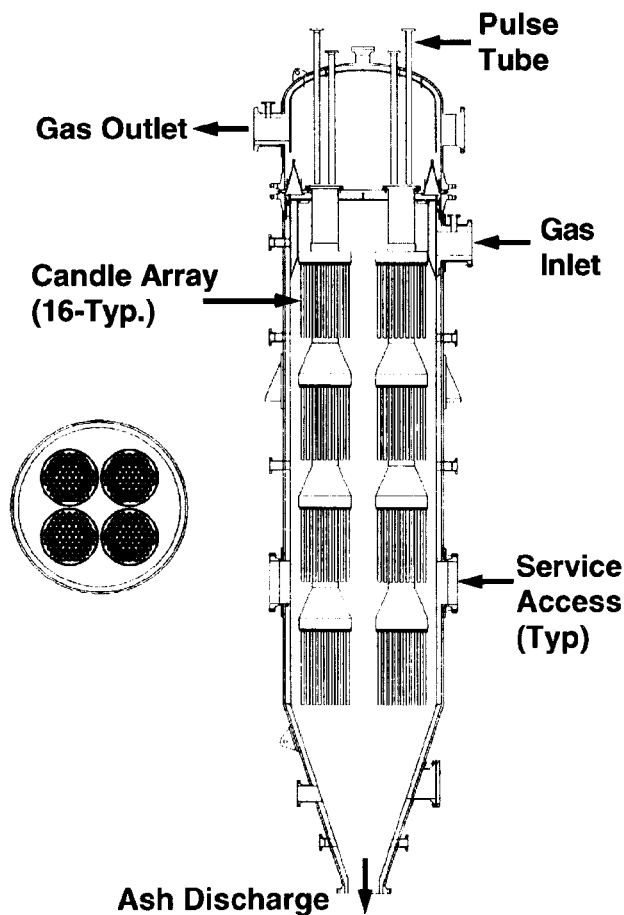
The first application of the maintenance hardware was demonstrated at the initial filter installation. Four teams of boilmakers were trained. They worked simultaneously inside the filter vessel and

accomplished assembly of all the 748 candle elements, demonstrating the overall approach to maintainability.

Pressurized Fluidized Bed Combustion

Westinghouse has conducted hot gas filter testing at two different PFBC facilities: at the American Electric Power (AEP) 70Mwe Tidd-PFBC demonstration plant located in Brilliant Ohio, and at the Foster Wheeler (formally Ahlstrom) 10 MWt circulating PCFB facility located in Karhula Finland. Testing at the AEP/TIDD plant has been completed and reported (Hoffman, 1995).

SPPC – PINON PINE HGF



- **10 Ft. Dia. (3.05 m) Refractory Lined Vessel**
- **Contains 748 (1.5 Meter Long) SiC Candle Elements**
- **Candle Elements are Arrayed on Sixteen (16) Plenum Assemblies Containing from 42 to 61 Elements**
- **Backpulse Cleaning – Recycled Fuel Gas**

Figure 3 - SPPC - Pinon Pine HGF

Hot Gas Filter Maintenance Features

- Candle Maintenance or Replacement Without Vessel Disassembly
- Simple Bolted Connection Holds Candles in Place
- Pulse Pipes Replacable From Outside Vessel

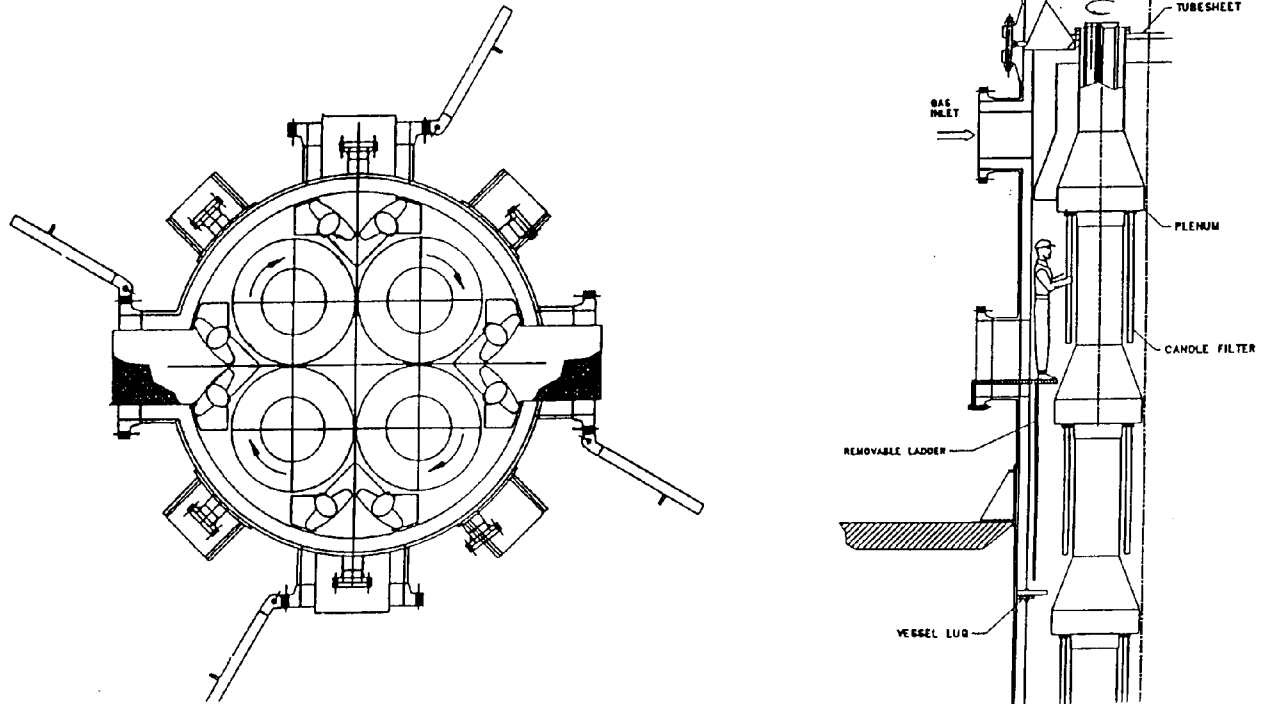


Figure 4 - Hot Gas Filter Maintenance Features

1. Karhula PCFB Testing

The hot gas filter testing conducted at the Foster Wheeler Karhula 10 MWt PCFB Facility is divided into three test periods:

1. Nov. 1992 through June 1994
2. Nov. 1995 through Oct. 1996
3. April 1997 - continuing

Table 5 summarizes the cumulative testing hours and coals used. A description of the Karhula facility and results from the earlier Nov. 1992 through June 1994 testing have been reported (Lippert,

T.E., et al, 1995). A summary of the Nov. 1995 through Oct. 96 and April 1997 (continuing) testing is given below.

**Table 5 - Summary of Westinghouse Hot Gas Filter Operation
at the Foster Wheeler PCFB - Karhula**

	Hours (Oct. '92 - Feb. '94)	Hours (Nov. '95 - Oct. 96)	Hours April '97
Illinois No. 6	306		
Iowa Rawhide	61		
Newland	300		
Kentucky	270		
Black Thunder	804		
Bituminous	170		
Pennsylvania	135		
Sparta		1166	
E. Kentucky			454
Total Coal (Period)	2046	1166	454
Total Coal (Cumulative)		3212	3666

The 1995/96, testing that included 1166 hours of coal operation was divided into three segments as summarized in Table 6. In Test Segments 1 and 2, with the Linwood Limestone in combination with the Sparta coal, ash bridging was experienced in the filter array leading to damaged and some broken filter elements. Subsequent evaluations that included ash, coal and sorbent analysis concluded that the ash bridging could have been the result of a higher than desired fraction of limestone fines entering the hot gas filter unit due to initial sizing of the limestone feed. To further evaluate the ash bridging experienced in Segments 1 and 2, the original Linwood Limestone was resized. Both resized Linwood and an alternative (Iowa Industrial) Limestone were utilized in separate test runs in Segment 3. The Iowa Limestone had been used in the 92/94 testing without incident.

The Segment 3 testing included periodic shutdown and inspections between runs. The sequence of testing, sorbent used and results of the inspections are summarized in Table 7. Operation with the Iowa Limestone was clearly more favorable than either the original or resized Linwood Limestones. The resized Linwood did appear to do better than the original Linwood Limestone. However, particle size measurements showed that the fines fraction entering the hot gas filter unit with the resized Linwood sorbent was not significantly different from the original Linwood Limestone. Inspection following this 626 hour test segment confirmed that there were no failed candles and no evidence of dust penetrating to the clean gas side. Throughout the 1166 hours of the 1995/96 testing, the filter operating pressure drop

remained stable, even with the ash bridging that occurred in Segment 2. Filter cleaning cycles ranged from 20 to 30 minutes.

Table 6 - Summary of Filter Operation (Nov. '95 - Oct '96)

Parameter	Units	Segment 1	Segment 2	Segment 3
Coal		Illinois #6 (Sparta)	Illinois #6 (Sparta)	Illinois #6 (Sparta)
Sorbent		Linwood Limestone	Linwood Limestone	Linwood Limestone Iowa Limestone Resized Linwood
No. of Active Elements		112	112	128
Operating Hours (Coal)	Hours	153	387	626
Filter Temperature	C	826 - 853	818 - 860	838 - 860
Filter Pressure	bar,a	10.7 - 11.1	10.6 - 11.3	10.5 - 10.7
Inlet Dust Loading	ppm	12000 - 13000	12000 - 15500	11000 - 12500
Pulse Interval	min	30	15 - 30	30
DP After Cleaning	mbar	90 - 123	79 - 157	61 - 87

Table 7 - Summary of HGF Testing Using Alternative Sorbents (Segment 3)

Sorbent Feed	Operating Hours	Inspection
Original Linwood	142	Clear evidence of initiation of ash bridging, similar to that seen in Test Segments 1 and 2.
Iowa	266	Dramatic change in ash characteristics, no indication of further ash bridging or ash accumulation.
Resized Linwood	218	Inconclusive, some evidence of the initiation of ash accumulation that would lead to bridging.

The objectives of the 1997 testing are to evaluate the PCFB boiler emissions and hot gas filter ash characteristics using the coal and sorbent currently anticipated for the DOE PCFB Clean Coal Demonstration Plant planned for the City of Lakeland Florida at their McIntosh Unit 4 Station and in

addition, continue the filter material qualification testing. The filter testing is planned in two separate test segments. The first test segment has been completed and focused on ash characterization, Table 8. Inspections of the filter were conducted following approximately 100 hours of operation and again at the end of the 454 hour test segment. No evidence of ash bridging was detected at either inspection. Dust deposits were minimal with a relatively uniform residual ash layer over the candle elements. Throughout the 454 hours of testing, the filter operating pressure drop remained stable and cleaning cycles ranged around minutes.

Table 8 - Summary of Filter Operation (April '97 - Continuing)

Parameter	Units	Segment 1
Coal		E. Kentucky (Beech Fork)
Sorbent		Gregg Limestone
No. of Active Elements		128
Operating Hours (Coal)	Hours	454
Filter Temperature	C	847 - 853
Filter Pressure	bar,a	11.3
Inlet Dust Loading	ppm	9400
Pulse Interval	min	20 - 30
DP After Cleaning	mbar	60 - 95

Segment 2 testing is scheduled to begin in August 1997. Detailed test plans are being prepared.

During the period of the Karhula testing, inspections of the hot metal structures have been conducted. These periodic inspections and evaluations have confirmed the integrity of the base metal (minor oxidation and embrittlement) and structural welds. Several of the clean side seal welds have exhibited cracks that have been subsequently repaired during regular maintenance outages. A warping of the hot metal seal plate (the device that connects the cluster to the existing Karhula vessels' water cooled tubesheet) has occurred but this does not presently appear to be a limiting factor to continued operation. Based on the Karhula PCFB testing and follow-up cluster assembly inspections, the hot metal structures have performed as designed.

The Westinghouse 128 - candle element cluster utilized at the Karhula PCFB facility was designed in 1991 and fabricated and installed into the Karhula facility in September 1992. Although candle elements have been changed, the basic hot metal structures have been utilized throughout the 3666 hours on coal operation (1450 to 1650F) plus another 1600 hours of high temperature operation on heavy and light oil used during startup, shutdown and other operating periods. During this period, it is estimated that the filter has experienced over 300 thermal cycles (startup, shutdown, hot restart, load changes etc.) under which metal damage accumulation is expected. Although it is difficult to extrapolate this test experience to a commercial, base loaded power plant, this test experience has helped to establish the commercial viability of the hot metal structures.

2. FWDC/Livingston HGF Testing

Testing supporting the development of the Topping PFBC (second generation PFBC) has taken place at the Foster Wheeler Development Corporation (FWDC) pilot plant facility located at the John Blizzard Research Center in Livingston, New Jersey. As part of this program, separate Carbonizer/Filter and Combustor/Filter component testing was conducted and then in integrated operation. Recently, however, the operation of the 22-element Carbonizer/Filter has been continued as part of another Foster Wheeler program. The filter testing is summarized below.

The Foster Wheeler Development Corporation (FWDC) is a participant in the DOE HIPPS Program for advanced pulverized coal-fired electric utility plants. In the FWDC concept, an air-fluidized sand-bed pyrolyzer, with injected pulverized coal and limestone, generates a low-Btu fuel gas, and a char-sorbent mixture. The fuel gas and most of the char-sorbent mixture flows directly into a hot gas filter. The cleaned fuel gas is then fired in a combustion turbine, and the char-sorbent mixture is burned in a conventional PC-furnace.

FWDC is testing a fluidized bed pyrolyzer pilot unit with a hot gas filter supplied by Westinghouse. The filter pressure vessel contains 22 filter elements, 11 on each of two side-by-side plenum chambers. The filter elements are 1-1/2 m long ceramic elements, 2 supplied by Coors and 10 each by Schumacher and Pall. Filter test results have been compiled in one shakedown test (HSD-2, March 1997), and in the first test run (TR-1, April 1997). Six set points were established during the TR-1 campaign. The test conditions and performance results are summarized in Table 9.

The hot gas filter commercial temperature is about 1000°F, and the FWDC testing has operated at filter temperatures up to 1400°F. No cyclone is used in the plant, and the ash loading to the filter is very high. The filter internals were inspected by boroscope following the testing and found to have no damaged candles and to be free of bridging and deposits. No significant difficulties with ash drainage from the vessel were observed during the testing. The FWDC pyrolyzer filter testing has shown that the Westinghouse hot gas filter can operate well even with inlet dust loadings greater than 100,000 ppmw. The high dust loading of coarse particles, 30-50 µm in mass-mean diameter, may minimize problems with bridging and vessel drainage. The filter cake permeability's are comparable to previous measurements made during carbonizer filter testing in the Advanced-PFBC program. FWDC will continue pyrolyzer testing at higher pressures (up to 200 psig) during the second test run (TR-2), scheduled for July 1997.

Table 9 - FWDC Pyrolyzer Filter Test Conditions and Performance

Test Period	HSD-2	TR-1
Filter pressure (psig)	40-60	60-120
Filter temperature (°F)	1200	1400
Face velocity (ft/min)	2.5	2.7
Inlet dust loading (ppmw)	40,000-120,000	40,000-180,000
Baseline DP (in-wg)	10-25	40-60

Pulse frequency (1/hr)	5-6	6-7
Continuous test time (hr)	62	80

Power Systems Development Facility (PSDF)

Westinghouse designed and supplied two particle control devices (PCD-301 and PCD-352) for installation and operation at the Southern Companies Service PSDF located in Wilsonville Alabama. The PCD-301 unit has been installed into the MWK Transport Reactor (TR) test loop. The TR is designed to operate in either a gasification or combustion mode. Testing to date has been in the combustion mode.

PCD-301 hot gas filter system is a two-plenum, single cluster unit containing 91 candle elements. The filter installation, and pressure and pulse-skid check-outs were completed in July 1996. The first operation on coal occurred Aug. 14-21, 1996 during which period the TR operated on coal for 80 hours. Up to the end of May 1997, the PCD has been subjected to more than 1000 hours in combustion with about 737 hours on coal feed with temperatures up to 1390°F and pressures to 170 psig. The on-coal run conditions through May 27, 1997 are summarized in Table 10.

Table 10 - Coal Run Conditions at the PSDF Through 4/27/1997

Run No.	Hours on Coal	Coal/Sorbent	TR Bed Materials	Max. Filter Temp. (°F)	Filter Pressure psig
CCTIC	80	AL Bituminous Dolomite	Alumina	700	150
CCT2C	146	AL Bituminous Dolomite	Sand	600	160
CCT4A/B	58	AL Bituminous Dolomite	Sand	930	160
CCT4D	173	AL Bitum. / Dolomite	Sand	1000	160
CCT5A	181	AL Bitum. / Dolomite	Sand	1350 - 1400	160
CCT5B	99	AL Bitum. / Dolomite	Sand	1396	160

The PCD-301 system in general has performed very well even under a variety of particle loading conditions. Typical loading has been 4,000 to 20,000 ppm. Occasionally, upsets during commissioning of the TR have produced transient loading to the filter as high as 100,000 ppm. The high loading has been mitigated to some extent by the large average particle size distributions coming over from the TR. Pulsing has been regular and effective requiring a tank pressure of 400-450 psig with a pulse frequency of one every 30 to 45 minutes. ΔP increases prior to pulsing have generally been relatively low, 10- 60 iwg

being typical. Limited particulate sampling made at the PCD outlet has confirmed overall PCD collection efficiencies to be >99.9%.

During shakedown operations, and startup and commissioning activities, there were two candle failure events which were caused by TR upsets. In the first event which occurred in August 1996, (Run CCT1C) 77 of 91 filter elements were broken when the filter vessel was filled with ash almost up to the gas inlet pipe. During this event the fail-safe devices located at the outlet of each candle element operated exactly as designed and prevented the ash from flowing downstream. The second event occurred in early April 1997 (Run CCT4C, not included in summary table) in which during startup coal fines were inadvertently fed into the PCD. The temperature was high enough to cause ignition of fines on the filter elements. The resulting thermal stress produced by the event was sufficient to damage almost all of the 91 filter elements. All the other Test Runs shown on Table 10 were completed without incident.

Application

The successful development and demonstration of hot gas particulate filters will enable achieving higher energy efficiencies and lower costs in Advanced Power Generation cycles such as IGCC, PFBC and Advanced PFBC. The technology has application for a wide range of solid fuels, including coal and biomass. In addition, many industrial applications could benefit from HGF technology application.

Future Activities

FWDC/Karhula PCFB

Test operations continue at the FWDC, 10Mwt PCFB facility at Karhula Finland that utilize the Westinghouse HGF candle unit containing up to 128 elements. HGF testing is focused on evaluating alternative candle materials to temperatures above 830°C. A 500 hour test run is currently planned for Fall 1997.

Power Systems Development Facility

Operation of the KRW TR and PCD-301 is continuing under the combustion mode. Plans for operation in the gasification mode are being developed.

PCD-352 unit has been completely fabricated and delivered to site. This unit will serve as the HGF for the Combustion Leg of the FWDC/APFB test loop. Installation is ongoing, with operation expected early in 1998. The PCD-352 is a 3-Cluster, 2-Plenum unit that can hold up to 273 candle elements. Clusters from the PCD-301 are interchangeable with clusters from the PCD-352 unit. Candles for the PCD-352 have not been selected.

Sierra, Pinon Pine 95 Mwe IGCC

Plant start-up is expected mid year 1997. The Westinghouse HGF unit is installed and ready for operation.

Acknowledgments

We wish to acknowledge the DOE/FETC CTO's involved in the various programs related to the hot gas particulate filter development for their technical guidance and support during the conduct of these programs; Mr. Richard Dennis, Mr. James Longanbach, Mr. Donald Bonk and Mr. Theodore McMachon. Also, the following organizations are recognized: Foster Wheeler Development Company; Southern Company Services; Electric Power Research Institute; M. W. Kellogg Company.

References

Hoffman, J. D., et al, 1995, "Tidd Hot Gas Cleanup Program - Final Report." U.S. DOE Contract DE-FC21-89MC26042. Prepared by the American Electric Power Service Corporation, Columbus, OH, October 1995.

Lau, F. S., et al, 1993, "Development of the IGT RENUGAS® Process." In Proceedings of Strategic Benefits of Biomass and Waste Fuels Conference, Washington, DC: Electric Power Research Institute.

Lippert, T. E., et al, 1995, "Westinghouse Advanced Particle Filter System," Proceedings of the Advanced Coal-Fired Power Systems '95 Review Meeting, DOE/METC-95/1018.

Lippert, T.E., M.A. Alvin, E. E. Smeltzer, D. M. Bachovchin, and J. H. Meyer, 1993, "Subpilot Scale Gasifier Evaluation of Ceramic Cross Flow Filter -Final Report," DOE/METC Contract no. DE-AC21-88MC24021, August.

Robertson, A., et al., 1989, "Second-Generation Pressurized Fluidized Bed Combustion Plant: Research and Development Needs," Foster Wheeler Development Corporation, Livingston, NJ. Phase 1, Task 2 Report FWC/FWDC-TR-89/06 to the U.S. DOE under contract DE-AC21-86MC21023.

Wiant, B. C., et al, 1993, "Biomass Gasification Hot Gas Cleanup for Power Generation," In Proceedings of First Biomass Conference of the Americas, Burlington, VT.